Lessons from Government Venture Capital Funds to Enable Transition to a Low Carbon Economy: The UK Case

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***Abstract*—Early-stage small and medium-sized enterprise (SME) cleantech innovation, if properly funded, can initiate disruptive low carbon reduction impacts across a wide range of sectors to meet Climate Change Net Zero requirements. The role of venture capital (VC) finance in successfully commercializing new technologies remains contentious, particularly where socio-environmental returns may well be greater than the economic returns which are the exclusive captures of the investors. This paper addresses a pertinent question facing government policymakers; how best to support VC to achieve Climate Change objectives? It focuses on the supply-side policy, design and implementation of four UK government-backed venture capital funds (GVCFs) at various stages of their development. A systems framework and absorptive capacity learning lens informs a grounded qualitative methodology, spanning a decade of over 100 in-depth interviews with policymakers, fund managers (private and public), alternative finance providers and low carbon finance market experts. A model is developed to assess GVCF learning evolution to address the nascent early-stage pre-commercialization cleantech venture investment market. This avoids the pitfalls of quantitatively analyzing the investment outcomes of these long horizon investment funds prior to their completion, by providing qualitative process findings that inform policy, practice and theory in the evolving early-stage low carbon GVCFs.**

***Index Terms*— SME Finance, Government Venture Capital Funds, Cleantech, Early-stage Innovation, Green Finance, Entrepreneurial Finance, Climate Change.**

I. Introduction

The required transition to a low carbon economy has come under increasingly sharp focus globally, particularly post the landmark Paris Agreement (2015) to restrict post-industrialization global warming to below 2 degrees Celsius. Substantial investment will be required to facilitate this transition [1],[2], challenging the current capitalist investment markets and widespread governmental *green growth* policies [3],[4] and raising concerns that private sector investment into low carbon solutions will not take place quickly enough to achieve net zero carbon calls by 2050, or sooner [5],[2]. One major response has been for governments across the globe to enact policies to increase environmental 'impact' investing. Understandably, their focus has predominantly been on large-scale infrastructure work to improve clean energy, transport, heavy industry and agriculture (e.g. UK Green Investment Bank and Global Climate Partners Fund, see [5], [1]), the largest greenhouse gas emitting sectors [6]. However, far less attention has been given to funding the early-stage small and medium-sized enterprise (SME) cleantech innovation which can make disruptive low carbon reduction impacts across a wide range of sectors. The role of venture capital (VC) finance in successfully commercializing new technologies remains contentious [7], [8], particularly where socio-environmental returns may be greater than the economic returns which are the exclusive captures of the investors [9]. This paper addresses a pertinent question now facing government policymakers [10]; how best to support VC to achieve Climate Change objectives? The paper focuses on the role of government-backed venture capital funds (GVCFs) and addresses Owen et al's [1] call to learn and apply lessons from their past evaluation to improve the cleantech financing market.

Advanced economies, notably in Europe and North America [11], where VC is more mature, have been at the forefront of cutting-edge new approaches to developing private low carbon impact investing [1]. Venture Capital (VC) represents pools of private finance raised by General Partner professional fund managers from private investor Limited Partners (e.g. institutional pension funds and family office investors). These typically form Limited Partnerships (LPs) as ten-year VC funds which the fund managers invest into early-stage potential high-growth (PHG) ventures, typically spanning the high-risk but potentially high reward financing stages of seed (concept and research and development (R&D)), venture (start-up and early commercialization) and (commercial) scale-up, prior to investment exit, typically via trade sale or initial public offering (IPO) [12].

Environmental impact investing is a recent phenomenon that has attracted VC investors. It incorporates socio-environmental aims alongside financial return [13]. A focus of such investment has been in cleantech ventures ('cleantechs'), defined here as

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undertaking environmentally friendly technological innovation and associated services and practices focusing on lowering carbon use and greenhouse gas (GHG) emissions [14]. Cleantech is typically capital intensive, long horizon and highly uncertain, raising investor attractiveness issues [2], [15]. Investor pitfalls were starkly revealed in Gaddy et al.'s [14] reported collapse of the $25bn US cleantech VC market 2006-11, which argued that VC provided the wrong model for longer horizon cleantech investment, being more suited to shorter horizon, digitech or later-stage investments [8]. VC is an industry of fashions, often attracted to shorter-term technology investment platforms, which appear stable, offer rapid portfolio company growth and quick exits, preferably in under five years. Recent decades have seen VC focus on internet and communications software investing, leading to the early 2000s Dotcom boom and bust [12] and more recent fixations, for example on smartphone Apps. However, whilst software dominates the VC 'tech' investment markets, longer-horizon (5-10 plus years to exit) life science and cleantech investments are also major segments [16]. Gaddy et al's [14] study spanned the Global Financial Crisis (GFC) and the subsequent revival of cleantech VC investment in the US and globally [17], allied to the current complexities of the COVID-19 Pandemic [10], [18], suggest the need for further insight into the potential for more effective cleantech VC investing beyond the Pandemic [19].

This paper focuses on the UK, a mature European VC market [2], [20], [21], perceived as a leading exponent of low carbon finance innovations [22], [23], notably through the recently established Green Finance Institute (2019). The paper examines the supply-side role of VC as a key pivotal private finance provider where public sector co-financing assistance through Government Venture Capital Funds (GVCFs) [24], [25], can make a difference. Lessons from the UK's post-GFC GVCF market, from 2009 onwards [26], [8], are used to demonstrate how to create a more efficient financing escalator [27], [28], to assist early-stage cleantech ventures through the 'valley of death' from proof of concept to achieving secure market traction [29]. A systems framework [21], [30], [31], [32], [33], and absorptive capacity lens [34], [35], [36], is adopted to understand how GVCFs can achieve this objective. A *systems and learning* model is developed to qualitatively assess GVCF learning evolution for developing the nascent low carbon early-stage pre-commercialization venture investment market. This avoids the pitfalls of quantitatively analyzing the investment outcomes of these long horizon investment funds before their completion [14], [2], by providing qualitative process findings that inform policy, practice and theory.

II. Methodology and approach

A qualitative mixed methods [37] approach is adopted to investigate the supply-side delivery of GVCFs to address the patient capital requirements of early-stage UK cleantechs. First, the extant literature is reviewed to assess the cleantech early-stage funding gap challenge and raison d'etre for GVCF instrument intervention. Second, Owen et al, [1], [2] call for cleantech GVCFs to learn from prior GVCF evolutionary lessons. This is addressed by establishing a conceptual systems framework [21], [30], [31], for applying an absorptive capacity lens [34], [35], [36] to analyze how policymakers and GVCF fund managers have learned, through their interactions within the entrepreneurial finance ecosystem [38], to enhance the design and implementation of GVCFs and improve the UK's early stage cleantech financing escalator [27].

Since UK cleantech patient capital GVCF is nascent, operational only since 2009, the focus is on qualitative process analysis, avoiding quantitative data deficiencies on exit outcomes, unlikely to be realized yet [26]. The UK's four main cleantech GVCF programs are examined: Investment Accelerator (IA); Low Carbon Investment Fund (LCIF); Clean Growth Fund (CGF); UK Innovation Investment Fund (UKIIF). GVCF information is drawn from 103 in-depth interviews, undertaken face-to-face, by telephone or video-link, with policymakers, fund managers, and stakeholders such as business support services, other investor groups and their trade associations (Table 1). The approach forms longitudinal and grounded case analysis [39] which, over a period extending up to 10 years, reveals layers of organizational learning [40] and also the process of interactions (or inactions) leading to change and realization of absorptive learning capacity [34], [35].

Interview topic guides provided a consistently structured and flexible approach for exploratory qualitative data collection and analysis [39]. They profiled respondents' experience and probed on the logic models and objectives of each GVCF program, their design, intended operation, ongoing evaluation findings and plans. A key focus of data collection, from multiple interviews over time (Table 1), was program lessons, using Theory of Change (ToC; [41]) and accompanying implementation logic models to evaluate the feedback loops leading to effective GVCF evolution. Interviews typically took 1.5 hours and were transcribed, authenticated with participants, and triangulated between different stakeholder viewpoints and extant published evaluations and program management data to provide a robust evidence base [37].

Grounded case evidence has subsequently been analysed in a unique way which acknowledges the contextual entrepreneurial finance ('entfin') ecosystem framework [21], [33], [30], in which (cleantech) GVCFs exist in the UK and the dynamic interactions, particularly between policymakers, fund managers and their portfolio companies, that lead to GVCF development. By adopting an absorptive capacity lens this interactional qualitative process analysis goes beyond VC organizational change studies investigating new market investment [42] and reverses the preoccupation with the flow of VC intangible knowledge into firm performance [43], [36]. Here, the emphasis is on the absorptive capacity of the policymakers and fund managers and the transition between potential and realized learning capabilities of the fund managers [34]).

The findings from the study therefore have important ramifications for policymakers, set out in the discussion, since the primary logic driving the GVCFs [44], [21], is that these programs select and develop private VC with appropriate experience and skills to develop a sustainable early-stage cleantech finance market. In other words, the GVCF fund managers have the absorptive capacity to realize their dynamic

capabilities and are not constrained by external (notably policy) context, or their personal or organizational internal path dependency [45],[35].

III. The Role of GVCF in the UK early-stage cleantech finance market

Since first reported by the Macmillan Committee (1931, [46], recent studies [27], [47], [48], find a persistent financing gap for UK early-stage innovative potential high growth (PHG) SMEs (<250 employee ventures). This gap is most acute where information asymmetries (IAs) are greatest between potential investors and founder entrepreneurs, during early R&D stages through to the establishment of commercial market traction [49]. North et al., [27] find IAs are exacerbated for UK Technology Based Small Firms where early-stage ventures lack trading record and collateral to raise debt finance. Mazzucato and Semieniuk [29], find this 'valley of death' period [50; 227] particularly problematic for cleantechs due to their typically large, long horizon, investment needs for early-stage R&D, capital-intensive prototypes and demonstrators. Indeed, Owen et al., [51], [2], present examples of investments into renewable energy, advanced manufacturing and battery storage technologies ranging upwards of £15m and over periods in excess of 10 years.

Unsurprisingly, private finance, primarily motivated by maximizing returns from investments, assesses the high - risk, due diligence, and investment costs - and long periods for investment returns from cleantech as prohibitive [2]. Cleantech risk-reward balance is less attractive than other shorter horizon sectors (e.g. digital) or later stage innovation investments. Polzin [9], also highlights that environmental impact investors do not gain any direct financial benefits from the wider environmental external benefits of their investments (e.g. reduced air pollution and health treatment costs). Herein lies a criticism of the green growth policy paradigm exemplified by the UK's Clean Growth Strategy (2017), which consistently overlooks the need for effective carbon accounting [3], [4]. Whilst beyond the focus of this paper, government policy and regulations form critical system facilitators (e.g. UK feeder tariffs encouraging renewable energy micro generation for the national grid), or barriers [52], [2], to investors in early market green innovation adoption [2], [38]. Notwithstanding, government co-financing of early-stage private VC alongside investor tax breaks, grants, soft/deferred loans or hybrid mezzanine finance (convertible loans), offer a potentially significant part of the solution to bridging the cleantech early-stage funding gap [1], [53], [54]. Venture Capital Trusts (VCTs) offer a potential option as investor tax break vehicles, but these private VCs have no specific cleantech remit and are typically later stage investors [55], suggesting targeted early-stage cleantech GVCF might offer a more effective approach to develop this investment market [2]. However, the role of GVCFs remains contentious, since government has to balance the cost of off-setting VC risk for public good, versus the opportunity costs of adopting other policies [29], [2].

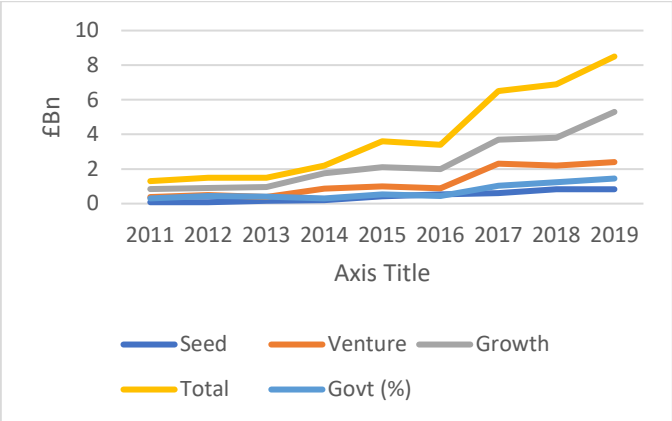
The UK SME equity investment market for seed, venture (early commercialization) and later commercial growth (scale-

TABLE I
Breakdown of UK Cleantech VC Ecosystem Stakeholder Interviews

Fund/Investor/Stakeholder	Location
UK Innovation Investment Fund (UKIIF):	
11 Interviews: 2012 (8), 2014 (2) 2020(1)	
Hermes GPE Environmental Innovation Fund	Fund of funds manager, London
European Investment Fund UK Future Technologies Funds	Fund of funds manager, Luxembourg
Underlying funds:	Hermes fund, London
Zouk Cleantech II	Hermes fund, London
Scottish Equity Partners (SEP) Environmental Energies	Hermes fund, Glasgow and London
WHEB Ventures	EIF UKFTF fund, London and Cambridge
DFJ Esprit	EIF UKFTF fund, London
Advent Life Sciences	EIF UKFTF fund, Utrecht and Cambridge USA
Gilde Healthcare III	
Investment Accelerator (IA) VCs:	
4 Interviews: 2018 (2), 2020 (2)	
Midven (formerly Rainbow Fund)	Birmingham
Oxford Science Innovation (OSI)	Oxford
Low Carb Investment Fund (LCIF)	
2 interviews with University of East Anglia in 2020	Norwich
Clean Growth fund (CGF)	
2 Interviews: 2017 (1), 2020 (1)	
Carbon Limiting Technologies	London
Other Government Backed Investors:	
34 Interviews: 2014 (30), 2019 (4)	
8 Enterprise Capital Fund VC Funds Managers	4 London, 2 Cambridge, 1 Oxford, 1 East Midlands
19 Angel Co-Investment Fund Lead business angel investors from investment syndicates, of which 16 were successful ACF applicants and 3 were unsuccessful	10 angel groups, 5 in London, 2 in South East, 1 East Midlands, 1 South West England and 1 in Scotland
3 Investment Committee (IC) members - experienced angel or institutional investors	UK-wide representation
4 Regional Investment Funds in Northern Powerhouse and Midlands Engine RIFs	2 North and 2 Midlands funds
Government Agencies and Policymakers	
10 Interviews: 2010 (2), 2014 (3), 2018 (2), 2020 (3)	
British Business Bank	Sheffield
UK Dept. for Business, Energy and Industrial Strategy (BEIS)	London
UK Dept. for Environment, Food and Rural Affairs (DEFRA)	London
UK Dept for Culture, Media and Sport (DCMS)	London
Innovate UK (IUK)	London
European Investment Fund (EIF)	Brussels
Alternative Investors and Experts	
43 Interviews: 2014 (20), 2020 (20)	
13 alternative private investors: Private VCs (4) and seed VCs (3), Venture Capital Trusts (3) Angel Capital Groups (3)	8 in London, 2 Midlands,1 East of England, 1 North of England, 1 Scotland
30 industry stakeholders and experts, including: British Venture Capital Association (BVCA), UK Business Angels Association (UKBAA), Angel News, Green Angel Syndicate, St John's Innovation Centre, Oxford Innovation, Professor Dylan Jones-Evans (Finance Wales reviewer), Prof Colin Mason (entfin ecosystem expert, Glasgow University)	UK-wide coverage 10 Regional English Growth Hubs for business support in London, North East, South East, Midlands and South West

up) stages was valued at £8.5bn in 2019 (BBB, 2020). The market has grown rapidly in recent years, post-GFC bottoming out (Fig. 1), despite UK EU exit concerns since 2016. However, early indications in quarter one (Q1) 2020 suggest the COVID-19 Pandemic reduced investment by 38% compared to Q1 2019 with seed investment most subdued (BBB, 2020), mimicking VCs' flight to later stage risk averse investing during the GFC [60]. Private VC provides the greatest share of SME market investments (43%), followed by equity crowdfunding (emerging rapidly from 2% in 2011 to 25%) and announced business angel investing (22%). Angel and equity crowdfunding investments are more prominent in earlier-stage investing (50% of equity crowdfunding investments are seed stage). Whilst the UK seed market has developed an increasingly diverse mix of investors, including a proliferation of corporate-backed accelerators in London's 'Tech City', many early-stage investors, including specialist seed VC and angel syndicates lack the resources to follow-on fund [8], [21]. Equity crowdfunding also remains an unproven springboard for larger-scale funding, raising concerns over Series A funding gaps, particularly for longer horizon cleantech [2]. The British Business Bank (BBB) 2020 Equity Tracker [16], highlights important contextual characteristics of the UK equity market. First, the majority of investments are in the London-Oxbridge innovation triangle (almost half in London). Second, almost half of investments are in the technology sector (notably software and communications). Third, VC is predominately a later growth stage investor. Fourth, GVCFs support around one in six investments (Fig. 1), with BBB funds supporting 11% of deals, rising to 16% in the English Northern Powerhouse Regional Investment Fund (RIF) area and 19% in the Midlands Engine RIF area – much of it directed at earlier stage investing, with half invested in technology sectors. Software (£2bn) investments dominate the tech sector, with cleantech representing just £150m of investment in 2019.

FIGURE I
UK ANNUAL SME EQUITY INVESTMENT BY STAGE AND GOVERNMENT PROPORTIONAL SPEND

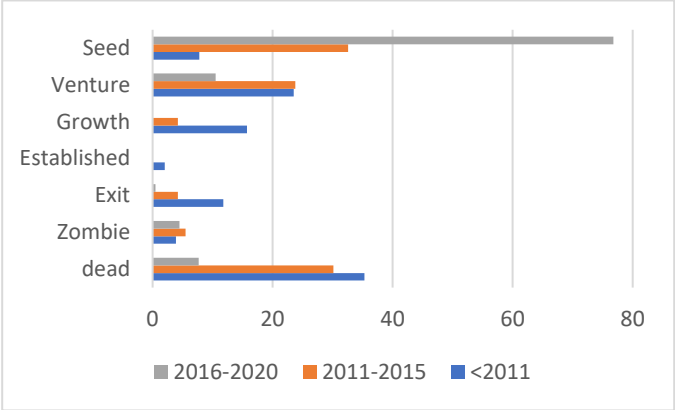


Note: Sourced from British Business Bank (BBB, 2020) Equity Tracker Report, Beauhurst data. Government proportional contribution proxy from announced/known equity deals, includes Devolved Nations (Scotland, Wales, Northern Ireland) European Union (EIF/ERDF), BBB Regional Investment Funds and Angel Co-Funds, but excludes unannounced ECF, UKIIF and later stage Patient Capital Fund investments.

The UK cleantech market is nascent. Beauhurst's UK cleantech market data exhibits almost £4bn invested in 731 SME ventures with announced fundraising rounds since 2011, with some cleantechs evolving since the early 2000s (Fig. 2). Cleantech investing is demonstrably high-risk, expensive and long-term [44]. Only 12% of seed investments from before 2011 had exit

ed, whilst 35% had ceased trading. These cleantechs average 3 fundraising rounds with median funding requirements of £197k at seed, £750k at venture and £2.3m at growth stages. There was considerable evidence of angel, accelerator and government-funded investments at earlier stages, notably from regional and also university seed funds. Crucially, around 5% of cleantechs at all stages (Fig. 2) are classified as 'zombies' (inactive >1 year), suggesting they may be engaged in long funding searches. Since these ventures previously recorded formal external investment rounds, it is reasonable to assume that some remain viable and subject to a funding gap. Evidence from Owen et al., [2], [48], [51], supports this finding, noting subsequently funded GVCF cleantechs (e.g. Anesco and Petainer) have thrived, with a small proportion of stellar outliers generating substantial net new jobs, wealth and innovation spillovers, supporting the case for GVCFs [44], [26], [51].

FIGURE 2
UK CLEANTECH PROGRESS (%) BY 2020 BY FIRST FUNDING SEED ROUND YEAR COHORT (N=507)



Note: 507 valid UK cleantech SME venture cases where current data on outcomes is provided by Beauhurst

IV. GVCFS PROBLEM OR SOLUTION? THE IMPORTANCE OF QUALITATIVE SYSTEMS AND LEARNING

Various commentators [44], [30], [7], [53], [56], [57], [58], [59], find that private VC funds are a well-established source of risk finance. VC fund managers, acting as expert financial intermediaries [44], [2], [57], have the ability to use their track records to raise substantial funds from large private institutional investors (e.g. pension funds, family offices) and use their expertise to invest in earlier stage PHG innovative ventures that operate in the space between smaller business angel and equity crowd funding seed investments (typically <£1m) and later stage private equity or Initial Public Offerings

(IPOs) on stock markets (typically >£10m; [60], [8]). Zider [61], summarizes VCs' role:

"Venture capital fills the void between sources of funds for innovation (chiefly corporations, government bodies, and the entrepreneur's friends and family) and traditional, lower-cost sources of capital available to ongoing concerns. Filling that void successfully requires the venture capital industry to provide a sufficient return on capital to attract private equity funds, attractive returns for its own participants, and sufficient upside potential to entrepreneurs to attract high-quality ideas that will generate high returns. Put simply, the challenge is to earn a consistently superior return on investments in inherently risky business ventures."

The problems for private VC arise where there is early staging, emerging sector and long horizon, capital intensive, investment [1], [2]. These factors coalesce to form a perfect storm of IAs leading to sub-optimal performance of the VC market, whereby funding gaps for viable PHGs occur [62], [63], [27]. A solution favored in more mature VC markets (e.g. Europe, North America and Oceania) has been GVCF instruments [44], [64]. Developments in GVCF in Europe since 2000 [24], [25], [20] and particularly in the UK after GFC adjustments [26], [51] are well documented. This period has seen the emergence of hybrid GVCF [24], [25], which co-finance government and private VC and follow Lerner's [44] advocacy that the private sector experts take the lead in selecting portfolio venture investments, with GVCFs nurturing then withdrawing once private VC is sustainable.

GVCFs have been highly criticized for underperformance, particularly when compared to private VC investment exit returns (e.g. [7], [8], [21], [12], [28], [65], [66], [67], [68]). However, others [8], [26], argue that the older vintage of GVCFs required to analyze exit outcomes are outmoded program designs. Furthermore, there is often lack of appreciation for the different public good role of GVCFs which address socio-economic and environmental concerns and regional disparities [62], [63], [2], [69], [30]. This suggests a more qualitative approach is required to account for the policy role and design implementation context of GVCFs, within an appropriate system setting [21], [70], [71].

V. Applying Systems and Absorptive Capacity to GVCF Design, Implementation and Learning

GVCF literature [71], [70], [24], [25], [57], [59], [72], [26], [8], [21] points to its catalytic role in delivering earlier stage venture private investment. Lerner [44] reviews more successful GVCF programs, finding the US Small Business Investment Company (SBIC) led the way in the late 1950s. More recent examples include Israel's Yozma funds, Australia's Innovation Investment Fund, the New Zealand Venture Investment Fund (NZVIF) and the UK Enterprise Capital Funds [26]. Kraemer-Eis et al., [73; 36) also commend EU European Investment Fund (EIF) first time VC assistance; "…many of the commercial VC firms being the pillar of Europe's VC industry today would not be there without having been initiated by EIF." However, Lerner [44] and Murray [25] caution VC is a long game taking decades to establish. Murray [25] also observes recent success is borne out of previous failures, suggesting organizational, absorptive learning capabilities [35], [40], by policymakers and VC fund managers has underpinned evolving GVCF hybridity.

Murray [24] discusses emerging GVCF hybridity, distinguishing between those directly managed by government bureaucrats or, as Lerner [44] prefers, private VC fund manager-led via co-financing arrangements. Murray et al., [67] criticize directly managed GVCFs in Finland (e.g. Finnvera's discontinued regional funds), whilst the infamous UK NAO (2009) [74] report scathingly criticized UK regional funds. These studies highlight design failures such as; poor (often public sector-led) management practices [75], overly inflated underwriting attractions to private sector fund managers resulting in moral hazard poor investment failures [25], small-scale funds [72], [26], application to thin regional and sector markets [76], evergreen practices encouraging mission creep [67] and cherry-picking causing crowding out of private investment [77]. Collectively, these studies define current best practice GVCF design and operation.

Drawing on Theory of Change (ToC; [41]) the rationale, design and implementation of GVCFs can be evaluated. This summarizes the GVCF strategy, delivery and intended benefits over time and can be formulated into a basic logic model [78], [79], addressing calls for policy learning through regular GVCF program evaluation [44], [1]. It also provides a basis for a wider, systems and learning, framework to address this paper's requirements, set out below - addressing first the policy system and then the program design for GVCFs.

The 'Entfin' System boundaries and networks for targeting funding gaps

First, the strategic scope of the GVCF requires clear articulation. The instrument's rationale is to target a funding gap. The four UK cleantech GVCFs (UKIIF, LCIF, IA, CGF) address a relatively small, but emerging strategically important market for tackling climate change. They do so through niche approaches designed to avoid program duplication and maximize private sector investment crowding in [77]. A concern from UK and European market experiences is to avoid thin markets [44], [76], for specific sector, stage and regional funds. An entrepreneurial finance ('entfin') systems approach [80], [81], [21], [44], requires understanding of the pipeline linkages between universities and R&D establishments into creating cleantech start-ups and public and private professional (e.g. accountants, lawyers) support services assisting investment readiness [82], [21]. In this sense the recently established BEIS CGF is designed to address cleantech Series A commercialization investment requirements, following-on earlier BEIS Engineer Entrepreneur's Fund grants. UK regional funds historically suffer from a combination of local thin markets, poor management and design [74], [66]. The LCIF's Eastern region focus is restrictive, but it benefits from close proximity and linkages to Cambridge University and its host University of East Anglia for R&D, alongside local science parks and expertise of St John's Innovation Centre's business support [38].

Owen et al., [2], [38], highlight that UKIIF, established in 2009, overcame the potential limitations of the UK cleantech market by investing globally, including alongside European

public and private funds within its structure and actively seeking to syndicate with other international VCs. Syndication has multiple advantages of increasing investment scale, sharing risk and developing foreign market opportunities to enable scale-up [83], [84], [85]. It underpins the design of recent international GVCF collaborations such as between New Zealand and Taiwan and Israel and South Korea [21]. However, Murray [25] cautions that syndication carries potential pitfalls of diluted specialism and access to information and expertise in emerging technology markets. Cumming and Johan [57] also advocate investing across different stages to spread risk, since later stage investments where more data and market traction is known are typically less risky.

The entfin system, policies and actors must be networked [44], [21]. The required top-down policy integration in the UK comes from the British Business Bank [86] and Green Finance Institute [23], to share learning, enable policy matching and avoid policy silos [2], [38]. Arguably, the Pandemic has demonstrated in 'war-like' conditions, that integration of rapid financing with sympathetic regulation can support early commercialization of impactful innovations. From the local and regional scale it should include suitable public and private ecosystem actors [38] to promote GVCFs to investors and cleantechs [38], [87], [88], develop support services [44] and develop effective finance escalators [27], [28]. Mason [28], argues for the strong presence of angel seed investors, which alongside other private investors such as accelerators, Venture Capital Trusts and crowdfunds (offering smaller-scale private investor tax relief), VC and later stage private equity, can offer a fluent advance to a suitably liquid exit market (typically through IPO and trade sales). Owen et al., [38] and British Business Bank (BBB) [88], further point to requirements for integrated public policy support to improve opportunities for regional levelling up [23].

Since a crucial objective of GVCFs is to engage with the private sector to increase private investment and provide demonstration models for sustainable private VC in the targeted finance gaps [44], [51], network monitoring and outreach is vital to recruiting VC, who may come for example from emerging business angels, Corporate VCs or internationally [26], [89], [44].

Program Design and delivery logic

GVCF logic models set-out how each program will operate to meet objectives within their target funding market ecosystem [79], [78], establishing the inputs (funding), procedural causal links assumed to deliver, outputs and outcomes over a given period of time. Here the key GVCF best practice program design features are assessed.

(i)Experienced private VC fund managers leading on investment decisions [44]. Whilst Murray [25], cautions that in practice GVCFs find it difficult to recruit top performing VC, Lerner [44] found the attraction of experienced US VC to Israel's Yozma funds and New Zealand's Venture Investment Fund helped establish VC in these markets, whilst Owen at al., [51] found that the UKIIF attracted high performing European cleantech VC and that the UK Enterprise Capital Funds (ECFs) had transformed business angels into VCs and spun out fund managers into the UK early stage VC market. Lerner's [44] prescribed approach requires regular fund monitoring, but avoids government micro-managerial interference, allowing private fund manager experts to select and manage portfolio investments, add non-financial value (e.g. market, networking, management skills and recruitment), and focus on maximizing venture scale-up and exit value [43], [26], [51]. Lerner [44] advocates GVCF as a VC nurture and withdrawal mechanism, ending when private VCs are established, but in practice establishing early-stage private VC takes decades [51], [2].

(ii)Designing VC incentives to attract private fund managers. Israel's Yozma funds, which provided a model for the UK's ECFs, offered preferential terms for private investors. The ECFs incentivize performance via an upside cap on state returns [26], whilst European state aid law has required that EIF GVCF investments operate pari passu [51]. In such cases, including UK Regional Investment Funds, better fund performance is rewarded by top-up funding [88]. Such approaches have been criticized [87], [88] as rewarding more rapid investments, rather than accounting for their quality or outcomes.

(iii)Sufficient fund size and follow-on capability. A major critique of European GVCF is that they are too small [72], [26]. Arundale [85] reported European VC as half the size of their US counterparts, with US VC twice as likely to follow-on fund and better placed to spend time managing their portfolio, rather than search for funds. Murray [25] also points to established GPs with track records being more likely to obtain further LP funds. However, for emerging GP fund manager talent, supported by GVCFs, further LP fundraising after only five years of investing into longer horizon cleantechs appears less likely. Arundale [85] recommends individual funds should be at least £50m, but not exceed £300m. Lerner [44] and Arundale [85] caution that funds should not be too large to sufficiently manage their portfolios, which Markowitz [90] suggested are optimal at 30 ventures. Cumming and Johan [57] also highlight the importance of fund recycling, every 5-7 years, and ongoing government support to ensure that funds are renewed. It is worth clarifying that since VC investment is a long game, with the average investment being 5-7 years – and often longer for cleantechs [51], GVCF first funds are often fully invested by year 5 and typically require further support through another round of fundraising in order to continue to have funds for ongoing follow-on investment, as well as new venture investments to increase the size of the portfolio. Reviews of the ECFs [26] and LCIF [91] reveal concerns over insufficient follow-on funding, which often require multiple investments of £1m plus.

(iv)GVCF program longevity. Debates persist over the merits of 10-year LP funds versus evergreen funds. Murray [25] argues that few evergreen funds have succeeded and Murray et al., [67] found that Finland's regional Finnvera funds had suffered mission creep due in part to their evergreen design. Lerner [44], promotes LP funds as a stable internationally recognized and attractive legal format [92] providing suitable milestone incentives for proactive fund manager investments. A caveat is that funds require flexibility to extend beyond 10 years to accommodate economic down cycles and longer horizon investments. Indeed, Baldock [26] and Owen et al., [51] found that the GFC had extended the average length of GVCF investment exits by 1.5 years and also noted that the longer

horizon UKIIF is a 12-year LP extendable to 15 years, acknowledging that cleantech VC is a long game [2], [51].

(v)Fund structure varies considerably, with the UK in the vanguard of hybrid developments [24], [51]. Lerner [44], recommends private VC fund manager led co-financing structures which have been widely adopted. Variations may relate to state policies such as the EU requiring pari passu funding to comply with state aid rules [51]. Their simpler-to-negotiate common share formats can facilitate easier match-funding arrangements. Catalyst funds such as the UK's Business Patient Capital, ECF Catalyst Fund, Angel Co-investment Fund (ACF), Scottish Co-investment Fund (SCiF) and London Co-investment Fund are typically pari passu and designed either to top up new or existing private VC fund closes to increase their size and speed-up their market impact or, in the cases of the ACF and SCiF, to match fund accredited experienced business angel syndicate rounds [8]. Catalyst funds offer flexibility and fast response to private-led VC investment requirements, offering increased investment scale and speed to the market. Notably, Innovate UK's Investment Accelerator is a novel hybrid fund which matches early seed grant allocation into cleantech infrastructure and health ventures with preferred supplier VCs, thus increasing early funding round scale and also encouraging earlier VC investment. Fund of funds, on the other hand, can leverage larger scale funding for multiple rounds, appearing particularly suited to longer horizon cleantech investment [51]. For example, UKIIF's double layer of investment fundraising through umbrella funds and suites of specialist underlying funds were double the size of ECFs [51]. UKIIF attracted high performance VC fund managers from across Europe, due to the scale of funding and market access opportunities under the guidance of skilled umbrella Funds like Hermes [51], [2]. A potential downside is the double layer of administration fees and charges [93]. Conversely, suites of smaller-scale funds offering debt, equity, mezzanine and even grants across innovation stages have, if well integrated, led to effective smaller regional finance escalators, such as in the North East of England [87]. A problem for smaller regional funds is whether they can attract larger later stage venture and scale-up growth funds through inward investment.

VI. Applying a Systems and Learning Approach to UK Cleantech GVCF

Critical review of GVCF programes and ToC [41] policy consideration for the roles of the four Cleantech GVCF programes (UKIIF, LCIF, IA and CGF) within the boundaries of the UK entfin ecosystem reveals antecedent (pre programe) and programe absorptive capacity [35] learning lineage [25], [2], [51], particularly over the past two decades. This indicates that long horizon cleantech investment is nascent and GVCF programs operational since 2009 will not offer viable IRR and exit data [51]. The approach is therefore qualitative, exploring through multiple interviews longitudinally how each of the four cleantech GVCFs have evolved. This is achieved through a unique combined system and learning framework (Table 2) exploring policy system – relating to the requirement for a holistic approach [21] considering entfin ecosystem boundaries and actors and cleantech GVCF program design [21]. By additionally adopting an absorptive capacity learning lens [35] the findings are analyzed from the supply-side perspective to explore the learning processes and changes made by policymakers and VC fund managers. This addresses policy evaluation learning requirements [44], [2], by enabling greater understanding of the dynamic processes and actor interactions leading to potential or realized learning outcomes [34] and how this relates to best practice evolution for cleantech GVCFs.

TABLE 2
A *SYSTEMS AND LEARNING* CONCEPTUAL ANALYTICAL FRAMEWORK FOR CLEANTECH GVCF

System Element	Dynamic Learning process and outcome
	Progression from antecedent lessons applied by policymakers and VC to consideration of: (i) path dependency (ii) potential; (iii) realized learning
Policy System (Policymakers, lobbyists and support agencies views) >Strategic policymakers (Departments, agencies) >Theory of Change (Defined role of GVCF Program) >Entfin actors (Actors involved for effective delivery) >Regulatory environment (VC LP law, tax/subsidy, 'green'/industry regulations)	Lessons learned Networks and linkages developed over time, key actors and extent of learning outcomes as potential or realized as best practice
Program Design (Program manager, *VC, trade association, market experts and *actors views*) >Logic model implementation (intended and actual) >Private VC and incentives >Fund size and follow-on function >Fund structure and longevity	Lessons learned Public program and private VC relationships, wider entfin market networks and linkages, relationships with portfolio cleantechs and extent of learning outcomes as potential, or realized as best practice

*Note: market actors include treated and untreated cleantechs (details excluded from this analysis)

VII. Policy System Findings

The nascent, niche nature of the UK cleantech market is highlighted by less than £300m UK government investment in the four cleantech GVCFs over the past decade into a growing market of almost £4bn [38]. From the policy system perspective each fund's ToC indicates their distinct UK entfin market objectives (Table 3). UKIIF and CGF are venture funds, whilst LCIF and IA are earlier stage seed funds. However, their common aims build on antecedent hybrid GVCF policy learning [24], [25], including; "to leverage private finance into earlier stages of the UK cleantech market through de-risking co-financing approaches" and "to improve VC investment skills and provide sustainable examples for the private sector to follow", thus supporting Lerner's [44] proposed GVCF nurture and withdrawal role.

(insert Table 3 – probably full page spread)

Individual Cleantech GVCF Theory of Change (ToC)

UKIIF (established 2009) was described by program managers during early evaluation as "…*a long horizon Series*

A to scale-up later stage fund, designed to have sufficient size to attract high quality European private VC and their institutional backers and offer multiple funding rounds to deliver substantive low carbon businesses." Early evaluation in 2012 revealed slow establishment of underlying VC funds and considerable costs associated with the private-led fund of funds approach. However, UKIIF demonstrably delivered catalytic high private leverage fundraising impact, post GFC, and GVCF fund sizes previously unseen in Europe. An EIF policymaker commented in 2020 "*we have seen the [subsequent] success*." CGF's first close (2020) represents the UK Department for Business, Energy and Industrial Strategy's (BEIS) first Series A Cleantech fund since establishing the now fully invested UKIIF. CGF is more narrowly focused (than UKIIF), investing only in UK cleantech, focusing on renewable energy and energy efficiency sectors. BEIS policymakers describe the fund as "*…designed to provide significant VC funding for cleantech commercialization, including supporting BEIS Energy Entrepreneur's Fund earlier stage grant funded cleantechs to realize their potential.*" This new fund, drawing on the skills of the appointed experienced cleantech seed VC has installed rigorous cleantech selection criteria, hitherto only loosely applied to UK GVCFs [38].

LCIF was established in 2009 as a seed to Series A fund. EU European Regional Development Fund (ERDF) support required a narrow East of England remit and socio-economic aims to assist women entrepreneurs, create jobs and raise skills. Situated in the A11 corridor linking the host University of East Anglia in Norwich with Cambridge University, the fund aimed to assist low carbon academic spin-outs and early-stage ventures attracted to local science parks. Designed as an evergreen revolving fund, tasked with potentially constraining thin market social objectives, it has had to widen its sectoral coverage and develop a nuanced, pioneering approach to cleantech investment selection. The Innovate UK (IUK) Investment Accelerator (IA), piloted in 2017, aimed to increase VC early-stage seed funding at post proof of concept grant funded stages. It aimed to place its successful grant funded ventures on a first step of private VC by co-financing grants with preferred supplier seed VCs operating in low carbon infrastructure and health sectors. IA's program managers sought "*to de-risk and raise seed VC investing and skills and certificate potential high growth cleantech and health ventures, advancing through their technology readiness levels, for follow-on investment.*" IA's early evaluation revealed lack of regional attraction, outside of England's London-Oxbridge innovation triangle, leading to extension of the program to include accredited regional business angel network investors.

Regulations and Support Systems Linkages

The experiences of the UK cleantech GVCFs demonstrate the need for a GVCF entfin system policy approach with regular fund appraisal [44]. Cleantech markets are emergent and dynamic. Niche defined GVCFs require carefully designed holistic support, particularly to create a pipeline of PHG cleantech investible ventures through incubation and investment readiness support [80]. Stakeholders explained that regional funds, like LCIF, require local university and R&D establishment spin-outs, incubator and support agencies such as St John's Innovation Centre, Allia incubator and Cambridge Cleantech's finance and supply-chain linkages (agencies also supported by EU and UK government programs), alongside an established angel seed investment network and specialist private business support services in cleantech investment accounts and law. However, it is a salient lesson that even within an established innovation region, the LCIF struggled to meet objectives and required policy adjustment. Notably, IUK's national IA GVCF also failed to attract low carbon infrastructure ventures from outside of the London-Oxbridge innovation triangle, with one Southern region VC respondent stating "*IA encouraged us to invest earlier and into new sectors such as transport because the opportunity was local*." Early evaluation findings thus led to seed investor linkages being established in other regions.

Multiple interviews (between 2012-2020) with UKIIF VC (including 7 case study ventures) revealed some stellar early exits (e.g. Anesco and Petainer), but also regulatory barriers. These were expected in bioscience, but regulations preventing small cleantech penetration into electronics and construction sectors "…suggest that government could do more to support cleantech adoption." Conversely, some ventures had flourished in more conducive markets such as renewable energy when UK feeder tariffs subsidized market innovation and take-up.

Overall, entfin ecosystem policy requires overarching program oversight [44], [86], [21], [2], to ensure that cleantech GVCFs are correctly designed and supported. Interviews with various government departments and agencies demonstrate lack of policy cohesion and sharing of lessons. Indeed, interviews sometimes "*Informed policy teams*" and "*…led to sharing of internal reports and experience*." Major concerns remain that the British Business Bank has since establishment in 2013 employed the most experienced UK GVCF policy staff for design, delivery oversight and evaluation of mainstream PHG venture supporting equity funds (i.e. the flagship circa £1bn Enterprise Capital Funds), but appears to show no interest in delivering new cleantech funds, or assisting BEIS or IUK to do so. This is a problem because these UK government departments and agencies experience high turnover of staff and appear to suffer from a lack of organizational learning and memory [35], exacerbated by policy silo practices. A challenge for the recently formed Green Finance Institute (2019) is to develop cohesive policy where programs challenge prevailing private market forces which reinforce support and investment into UK higher innovation regions and shorter horizon investments [25], [2]. For example, the British Business Bank's Regional Investment Funds have found "*Having a strong local network of business support hubs catalysed through other government department funded programs can be a vital source of potential high growth firm investment readiness and referral… but the quality and range of these services is patchy*."

Finally, stable financial markets with internationally acknowledged legal structures for VC facilitate foreign investment [44], [92], [51]. This is demonstrated by UKIIF's LP structure, designed to facilitate European VC collaboration. LP structures are attractive to limited partner fund investors as they establish a timeline for investment returns. Contrastingly, LCIF's evergreen structure was designed as a regional seed fund, in expectation of leveraging at least 50% of funding rounds from the private sector. In practice private investment

matching through venture investment rounds has proven problematic for niche funds (e.g. UK Aspire Fund for women entrepreneurs). Collectively, national policymakers appear to have learned that matched funding should take place either in an LP structure in fund formation, or as a top-up for accredited investors bringing deals to the fund (which is possible for IA deals). This latter point links into GVCF *program design*.

VIII. Program design

Private sector role

Following Lerner's [44] principles, all four cleantech GVCFs are led by private VC fund managers with expertise in cleantech and earlier stage investing who select portfolio company investments and oversee their development. They utilizing private fund manager expertise, with minimal public sector oversight and monitoring intervention. However, different GVCF operations demonstrate their evolving hybridity [25] designed to accommodate different policy objectives and target actors. UKIIF's private-led Hermes Environmental Innovation Fund provides experienced and well networked fund managers who assess and make investments into underlying VC funds. Underlying fund managers reported UKIIF as; "…enabling more rapid fund close and increasing the scale of funds…" whilst also offering "…expertise and networking support… and certification" to a wide range of VC, private equity and institutional investors. UKIIF enabled funds to deliver the desired volume and scale of cleantech investments in the £500k to £5m range to ensure optimal diversity and spread of risk for portfolio companies [93; 22-23). In contrast, IA and LCIF operate as partnerships with public bodies, but with the private sector selecting and supporting the portfolio investments. This partnership reflects the earlier stage investment process (seed to Series A) and requirement for IA to match Innovate UK's peer reviewed grant applications with preferred private VC and angel syndicate investors and the University of East Anglia's desire for LCIF to meet university spin-out requirements by utilizing commercial investment acumen supplied by Turquoise, a cleantech specialist investment bank [91].

The fund designs offer other VC inducements. For example, IA seeks to encourage earlier stage seed investing by offering an enhanced promotion and application process for cleantech, providing a first stage of due diligence and technical certification via peer review, whilst LCIF offers the management and cleantech support skills of university R&D to provide a pipeline of innovative venture incubation and ongoing technical support. Interviewed VC were attracted to IA as "…it promised a pipeline of good quality investment ready opportunities", but queried the technical peer review merit which "…frequently lacked commercial acumen." Innovate UK's longstanding, potentially path dependent, peer review for SMART innovation grants should be as credible as Germany's Fraunhofer Society. In the UK reviews should come from government established specialist technology Catapult centers and universities with industry experience, including emerging Innovation Knowledge Centre programs (e.g. Swansea University's energy technology IKC). While this remains a potential learning, LCIF exhibits realized learning through the university of East Anglia's development of market leading cleantech investment selection diagnostics [38].

UK government programs (notably UKIIF and IA) seek early-stage investor upskilling and demonstration to attract further private investors [44]. Underlying funds reported that UKIIF's Hermes umbrella fund offered cleantech market expertise, particularly in "…upskilling fund managers, enhancing networks for recruiting executives for portfolio companies, developing international market contacts and VC syndication." A major attraction of IA's two-thirds matching grant allocation was the ability to raise £150k of cleantech early seed finance whilst only requiring £50k of VC funding. In principle this required minimal due diligence beyond grant peer review certification, enabling increased numbers of rapid small investments without an investment committee selection process. This follows fund manager-led US West Coast seed investing approaches [85]; also exemplified by Passion Capital, a UK government-backed London 'Tech City' seed investor [26]. Program monitoring [88], [91], [2] demonstrates collective VC fund manager and government agency learning [35]. For example, IA seed VCs stated "…we invested in earlier stages and new sectors … learned quickly, for example what £150k investment could achieve and whether this generated sufficient data to reduce risk sufficiently for further investment." Early evaluation resulted in rapid program change to support follow-on funding to optimize opportunities to create a more fluent financing escalator for viable PHG ventures [28].

Fund Size and follow-on scale

Fund sizes vary considerably, reflecting target investment stages. Historically, small-scale specialist seed funds predicated upon finding follow-on investors have a poor track record [74]. Seed funds are vulnerable to share crushing by later stage VC's poor valuations and deal arrangements and missing steps in the finance escalator [51]. To avoid pitfalls of slow, drip-feed investment, funds must either be larger to invest through to exit (the 'Unicorn' model), or have well-established syndicating networks [85].

LCIF, a specialist East of England regional fund for seed and Series A investing, is smallest. LCIF's [91; p10-11] review mentions two decent exits but also highlights concerns in raising follow-on Series A funding: "Opportunities for further impact could readily be missed if sufficient funds are not available at the right time. Every effort is needed to secure additional funds for LCIF, in order to further develop the Fund's impact and reputation." The evaluation corroborates prior UK regional fund shortcomings [74], revealing thin regional and sectoral markets. A fund stakeholder explained how fund learning led to a "…revised expanded creative sector remit to meet ERDF low carbon women-led business investments." Nevertheless, more learning was required; ERDF's private investor 50% match-funding threshold generated high private investment leverage but restricted funding opportunities. This was alleviated through earlier stage investing, but then led to a Series A funding gap being addressed by a further £10.9m of ERDF investment in 2019.

IA began as a £50m pilot program matching Innovate UK grants with VC. Early IA evaluation [38], demonstrated that it encouraged earlier stage cleantech investing, but lacked follow-

on private investment. Participating VCs mentioned that "…insufficient data was being generated from initial seed rounds to encourage follow-on funding … despite their help with developing presentation pitchdecks and accessing investor networks." IA was subsequently enlarged to £75m with provision for flexibly timed applications for larger, later stage grant and VC matched funding.

In contrasting scale, UKIIF acting as a top-up fund, mainly for Series A and scale-up cleantech VC fundraising first and second closes, has been able to invest into underlying funds with an average first close size of over £60m [51]. These funds, such as Scottish Equity Partners and Zouk Capital (cleantech VC) can make substantial initial portfolio company investments, often above £2m, and follow-on fund without EU state aid restrictions. A further benefit is UKIIF umbrella fund's performance monitoring and ability to make discretionary top up investments to facilitate fund recycling.

Fund recycling, every 5-7 years, is crucial in allowing VC funds to grow and continue to follow-on fund their most promising portfolio companies through to optimal exit [57], [26]. The GVCF fund managers and stakeholders report that earlier stage cleantech investment is a long game [44], consistently expecting "…optimal exits to take 7-12 years." These GVCFs demonstrate absorptive learning capacity via increasing flexible market adaptation by regular 2-3 yearly evaluations to assess requirements for follow-on funding and adapting policy to facilitate this, as exemplified by IA and CGF's design aim to continue to seek further, regular fund closes and work towards a more optimal £100m size.

Fund Structure and Finance System Linkages

The different structures of the UK GVCFs relate to their aims to engage with different segments of the early-stage investing markets. They are designed by different agencies to tackle market niches, but operate in isolation from each other. Internal learning is evident from monitoring and program adjustments and there is evidence of institutional learning across the British Business Banks GVCF programs, leading for example to the enhanced size and scale of the flagship Enterprise Capital Funds program [26]. Discussions with policy staff offer no clear evidence of interdepartmental, cross-agency learning. Whilst a wide-ranging primary evidence (from policymakers, VCs, stakeholders) and studies [8], [21], [26], show little duplication, more concerningly [2], [38], there is little overarching policy attention to how these GVCFs integrate to complement and catalyze each other in the finance escalator [27].

UK GVCFs tend to have 10-year Limited Partner (LP) status, complying with Lerner's [44] preferred model which provides flexible timeline structures and milestones for funds, so that two-year extensions can be negotiated during economic downturns and to accommodate portfolio companies taking longer to mature for optimal exit. UKIIF, has an extended LP timeline of 12-15 years, acknowledging UKIIF's investing into capital intensive long horizon cleantech innovation companies [93]. Further notable differences are that LCIF and CGF are single purpose GVCFs operated by a single cleantech specialist private VC (i.e. Turquoise and Carbon Limiting Technologies), whereas IA and UKIIF are more directly concerned with engaging and upskilling a wider range of investors. IA aims to develop a model of match grants with seed VCs and accredited regional angel network business angel syndicates, and UKIIF's fund of funds investment model aims to develop specialist cleantech sector VCs across Europe.

A potential problem raised by Owen et al., [2], [38], is that these cleantech GVCFs and other UK GVCFs (mainly operated as sector agnostic by the British Business Bank), do not relate or refer to each other. As Murray [25] indicates, there are potentially conflicting public and private investment tensions. First, private VC are in competition to perform well and there may be a reluctance to refer, although recent evidence from Arundale [85] suggests that UK and European VC are now more closely following their US counterparts and syndicating and referring more often between VC and other types of investors (e.g. angel investors [51]). Second, government does not want to encourage state dependency, putting emphasis on follow-on funding leveraged from private investors. There is a suggestion, explored in the next section that more should be done to integrate GVCFs into the wider support and investment network in the UK [88], [38].

IX. Systems Learning

Applying an absorptive capacity, dynamic learning lens [35], [34], the findings offer insights into three types of learning – antecedent, potential and realized - and the pitfalls of path dependency and non-learning (Table 3).

Antecedent learning has taken place across the UK GVCF market, shaping policy and program design. This is manifest in all four cleantech GVCFs being private co-financed and private led – to make use of VC fund manager antecedent learned skills for selection, market knowledge and networking and non-financial portfolio business development support skills [43] – supporting Lerner's [44] principles. Policymakers have considered market roles, avoiding duplication and crowding out [77] and they have acknowledged the dynamics of the finance escalator [27] by undertaking regular GVCF monitoring and market evaluations.

However, there remains a concerning lack of antecedent learning in UK government department and agency teams, particularly where VC policy is nascent (IUK), or in hiatus (BEIS). This is exacerbated by staff turnover and the exodus of experienced senior GVCF policy staff to the BBB from 2013. This is manifested in repeated mistakes, which fail to take heed of the NAO (2009) [74] report's criticisms of small-scale poorly designed regional funds and dangers of niche thin market sector funds [67], with insufficient account for new venture pipelines, follow-on funding and exits [28]. In this respect, UKIIF's large scale and international design represents the zenith of BEIS GVCF knowledge, prior to establishment of BBB. Conversely, the ERDF funded LCIF is small-scale, regional, sector constrained, with additional EU social policy targets. LCIF's program managers noted "*…hard lessons were learned in order to adjust the fund*" but with regular monitoring (advocated by Lerner [44], Owen et al, [1]), these were successfully made.

Concerns remain that the UK seat of GVCF learning is the BBB, yet this specialist SME finance agency has "no remit to support low carbon financing" and appears not to advise

agencies that do so. BBB exhibits path dependency [35], focusing on delivering private funding leverage and financial return rather than low carbon. Meanwhile, BEIS, IUK and DEFRA policymakers "…*take consultants advice*…" and are typically "…*unaware of prior GVCF program evaluations*." The problem with consultancy reporting is the level of path dependency [35], undermining seeking and interpreting market information to support a policy vision, which may be poorly conceived.

Realized learning [34], provides policy and operational advancement. This study offers key examples where program monitoring and evaluation has led to adjustments. This is most notable in the LCIF's wider sectoral remit, but also in IA's adjustments to offer more substantial follow-on funding and develop wider reach by contracting with regional business angel syndicates. Perhaps one of the most important advances has been made by LCIF, which when established had no defined low carbon selection criteria. The program managers recognized this shortcoming and designed a sophisticated set of metrics which pre-empted later EU green deal requirements for the second funding round. Arguably, LCIF has raised the bar for other specialist cleantechs, since UKIIF required only a low carbon mission, with no subsequent impact assessment. LCIF's program managers also recognize "*developing portfolio company environmental impact, alongside innovation and financial metrics, has improved our monitoring and portfolio venture follow-on funding*."

Another learning realization route follows Lerner's [44] principle of attracting experienced fund managers. CGF contracted CLT, a specialist cleantech incubator, early-stage investor. CLT have established the most comprehensive portfolio venture selection and impact monitoring in the UK. CGF's fund manager and BEIS policymakers explained "…*comprehensive CO2 savings require innovation impact progress and supply-chain measures*". Circular economy impacts remain a potential learning aspect, although "…*material inputs into production and processes and wider environmental planning impacts have been taken into account.*" This demonstrates important progress for cleantech GVCF, but also shows how government's socio-environmental policy concerns – including "…*national energy security*" – offer different priorities from the private sector [25].

Potential learning [34] offers promise, but also concern. For example, the LCIF's problems with recruiting portfolio companies were only partially alleviated by taking on a wider regional sector remit. A further solution was to invest earlier stage, to reduce large sums of matched private funding required in rounds, but this in turn created a shortfall of later Series A funding. Delays in obtaining more fund investment, alongside retention of the round syndication private investment leverage model, may have potentially negative repercussions for portfolio companies, not yet fully understood.

X. Discussion: Developing Systems and Learning for GVCF

This paper addresses a pertinent question facing government policymakers; how best to support VC to achieve Climate Change objectives? Literature review established the persistent patient capital finance gap facing early-stage cleantech innovation [29], [1], [2], and potential role for GVCFs to address this [2], [51], [25]. Finding UK cleantech GVCFs are nascent and evolving, a qualitative, grounded case [39] research approach was undertaken, analyzing supply-side policy, GVCF program design and implementation. Focusing on four main UK cleantech GVCFs, established since 2009, the paper offers contemporary insights for GVCF policymakers and a novel contribution to evaluation theory in adopting a holistic entfin ecosystem framework [8], [80], [81] and an absorptive capacity learning lens [34], [35].

From an evaluation theory perspective, the paper avoids using quantitative data which is inappropriate for interim cleantech GVCF evaluation, given multiple issues with measuring long horizon investment exit outcomes, skewing from late exit stellar outliers [21] and the need to consider the wider socio-economic remit of GVCFs [62], [26], [30]. VC development is a long game, likely to take decades [26], and few UK cleantech GVCF exits have been recorded, indicating that R&D progression alongside improved socio-environmental measures are better interim evaluation guides [38]. Thus, cleantech GVCF is likely to increase its presence, rather than withdraw from the market in the next decade. The adopted *systems and learning* model offers coherent insights into policy learning and program design. For example, from a policy systems perspective, the different and evolving roles of the GVCFs can be traced, demonstrating their antecedent learning in respective ToC [41] to adopt de-risking co-financing demonstration models to encourage, upskill and develop sustainable private cleantech VC [44], [24], [20] and in niche positioning of GVCFs within the early-stage finance escalator to crowd-in private finance [27], [77]. CGF's recruitment of leading UK seed investment fund managers overcame BEIS departmental policy deficiencies, translating antecedent learning into new realized learning in developing a market leading holistic cleantech selection and evaluation approach (accounting for material inputs, site planning, innovation and supply-chain impacts), which (although not fully cognizant of circular economic factors) other GVCFs should benefit from [38].

The dynamic longitudinal *systems and learning* model further enhances policy evaluation by demonstrating the contribution of the cleantech GVCF within the entfin ecosystem and, crucially, the dynamics that create this. In this respect the inherent problems of the logic model implementation for LCIF and IA and their subsequent program design adjustments are instructive. Arguably, LCIF demonstrated path dependency [35] failings, not heeding warnings [24], [74], in establishing an evergreen small-scale regional cleantech seed fund, believing that local universities, R&D and science park facilities would provide a sufficient pipeline of ventures to meet cleantech and women's enterprise development objectives. Regular monitoring flagged thin market issues [76], leading to realized learning [34] design adjustments, but these subsequently led to a shortfall in Series A follow-on funding. A finding here is that matching funding in rounds (rather than in funds themselves) is problematic [51], [48]. Whilst this latter issue remains a potential learning point for LCIF, it was already an antecedent learning of IUK which designed preferred supplier seed VC into its IA program. IUK also used antecedent learning from its

grant schemes to assess portfolio technology readiness level progression towards commercialization and wider innovation cluster evaluation impact in IA's long horizon investments. However, IA also fell into the path dependent trap of lack of fund size to address follow-on funding, alongside insufficient entfin network linkages across UK regions. Both matters were flagged in early evaluation and delivered realized learning through fund enlargement and connectivity with regional angel investor networks.

From a policy perspective a key, *systems and learning,* finding is the lack of UK policy coherency for cleantech GVCFs. Under the UK Green Finance Strategy (2019) the focus, as with the former UK Green Investment Bank prior to privatization in 2017, is for green growth and leveraging private sector investment into large-scale infrastructure investments. Little attention is applied to coordinating early-stage cleantech innovation finance or ensuring that BBB GVCF programs have low carbon consideration alongside their aims to generate investment returns for the Treasury. Furthermore, UK GVCF design and implementation has been almost the sole domain of the BBB since 2013, it embodies Government's GVCF organizational learning [40], but is only responsible for one cleantech GVCF. Whilst UKIIF's design and operation represents the zenith of recent UK cleantech design, demonstrating antecedent learning in relation to fund size [44], private investment leverage, overcoming thin markets via transnational investment and offering global market syndication [51] and multi-stage follow-on funding through to scale-up and exit [57], UKIIF's funds are fully invested. The new emerging cleantech GVCFs are being developed by IUK (IA) and BEIS (CGF) and their respective policy teams do not have antecedent knowledge of GVCF design. The evidence suggests that policy knowledge and learning is limited in these departments, advised by consultants, and in one case a secondment from the private sector, with little cross-departmental learning. This lack of cohesion extends to patchy interconnection between specialist venture support policy such as through IUK's Catapult innovation support centres and BEIS local Growth Hub initiatives, which could assist with investment readiness and delivering improved venture pipelines [82], [48]. Finally, entfin systems policy requires a more supportive tax and regulatory environment that encourages UK cleantech ventures to flourish in difficult to penetrate long horizon sectors (e.g. construction, engineering) and encourages early-stage long horizon investing through improved carbon accounting and public awareness [38], [3], [4].

XI. Conclusion

The development of a systems and learning model for assessing the four main UK cleantech GVCFs' policy system, program design and implementation, provides important contemporary lessons on current good practice. The longitudinal approach also captures the dynamics of learning operating through key actor interactions, regular monitoring and evaluation that underpin hybrid GVCF development. Given the nascent, emergent status of cleantech GVCFs, this qualitative process focused analysis appears most appropriate for disseminating good practice within the UK and also globally, where cleantech GVCF are also emerging. In this way the paper addresses how best government should develop GVCFs to support cleantech commercialization for low carbon impacts.

However, more is required. The study highlights a lack of strategic government oversight in relation to enhancing organizational learning [40] to develop GVCF within the wider entfin ecosystem [96], [21]. This requires policymaker and policy connectivity and interorganizational and international learning [25].

The limitations of the study are highlighted by policy silos and lack of transparent public reporting on GVCFs and limitations in the use of appropriate indicators to properly assess their financial and public good roles within the wider entfin ecosystem [38]. Furthermore, publishing constraints permit only a supply-side focus, rather than a close examination of the progression and performance of the funded cleantech ventures. Thus, whilst this paper provides a research framework, overcoming these limitations remain the challenges for future research.

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Table 3: GVCF Systems and Learning Approach for Cleantech: A Developing UK Model

Theme/GVCF	**Investment Accelerator (IA; 2017)** National Seed Fund	**Clean Growth Fund (CGF; 2020)** National Series A Fund	**UKIIF (2009)** International Series A/Scale-up Fund	**LCIF (2009)** Regional Seed/Series A Fund
GVCF Policy System				
ToC/Logic model	Increase seed investment, raise VC and angels seed investing skills, market demonstrator, certificating cleantech and health PHG advancement through TRLs for follow-on investment. Offering seed grants of up to £100k matched with up to £50k seed VC.	Series A cleantech gap funding, UK-wide. Offering investment of between £250k to £2m (with no requirement for additional deal syndication finance). Delivers VC funding to commercialise BEIS energy entrepreneur grants.	Series A and scale-up low carbon long horizon gap funding, UK and global. VC upskilling and demonstration. Offering investment typically between £500k to £5m (no additional syndication required).	Seed to Series A cleantech gap funding, East of England Region. Offering £25k to £1m with minimum 50% matching private syndication funding required). Addresses ERDF aims assisting women entrepreneurs, jobs, skills.
Fund legal status	IUK grants matching private LP VC's or angel syndicates	10-years private LP VC	Extended 12-15 years private LP VC	Evergreen revolving legacy fund
Wider support policy/ regulations	IUK support, catapult/catalyst	BEIS clean energy policy, business regulatory support	BBB/EIF funding suite	Regional LEP, IUK catalyst/catapult
GVCF Programme Design				
Private Sector Role				
Private FM Lead	Private VC/angel network preferred supplier led: initial grant peer review, VCs FMs select investments (<£50k not requiring selection committee)	Single specialist private VC-led: FM selection committee	Private umbrella and underlying funds: FM selection committee	university/private VC: FM selection committee
Attracting FMs/ investment leverage	Two-thirds IUK innovation grant match, certificated by grant peer review – no syndication leverage requirement	At least 50% match to £20m BEIS clean energy innovation funding – no round funding leverage requirement	Pari passu top up to close European cleantech/health VC – no round funding leverage requirement	Pari passu ERDF funded, requiring at least 50% private match funding – no in-fund matching required
FM skills development	Encouraging seed stage investing experience in earlier stages and new low carbon/health sectors	Developing Series A cleantech experience in the energy sector, offering market demonstration	Encouraging experienced European VC in venture/scale-up into new markets with umbrella fund support	Developing early stage cleantech investing, across sectors with LC credentials – developed selection LC impact indicators
Fund Size				
Fund Size	£75m over 3+ years of funding rounds	£40m+ (planned for upwards of £100m over time)	£330m (average underlying fund £60m)	£31m in 2 tranches (tranche 1: £20.5m, 2009-2019)

Target Markets	UK cleantech infrastructure and health seed investing	UK Series A cleantech	UK (>= UK govt £150m investment) and global cleantech and health venture and scale-up	East of England region cleantech
Fund Recycling	Potential larger, later stage grant matches	Expectation of further private fundraising	Large underlying funds with follow on investing capacity	Limited funds for follow-on, second ERDF tranche 2019
Fund Structure and Finance System Linkages				
Structure	Funds private LP VCs and angel network syndicates	Single 10-years LP private-led GVCF	Fund of Funds, extended 12-years private LP	Single university/private GVCF
Finance Escalator Linkages	Matches grants with VC and angel equity	Links with BEIS Energy Entrepreneurs Fund grants	European/global VC networking	Regional university incubation (e.g. Cambridge)
Evaluation				
Independent evaluation	Early and interim evaluation (2018-2020, unpublished)	Planning early (2021) and interim evaluation	Early (2012) and interim evaluation (2017, unpublished)	Final (single) first fund evaluation (2015)
Dynamic Learning				
Antecedent Learning	Early, regular monitoring/evaluation Planned syndicate co-financing Private VC-led Progression, follow-on fund oriented VC, early investor upskilling	Early, regular monitoring/evaluation Co-financed in fund Private VC-led 10-years LP Planned large size, fund to exit oriented Enviro selection criteria	Early, regular monitoring/evaluation Co-financed in funds Private VC led 12-15 years LP for long horizon Large size funds to follow-on and syndicate to exit VC upskilling	Regular monitoring, fund evaluation Private investor led Cleantech pipeline-linked Socio-enviro mission goals
Policy Systems Learning	High additionality (>80%), FM learning from interaction with portfolio and market demonstration. Desire for greater regional coverage led to including/supporting regional angel networks.	Pre evaluation stakeholder, logic model. Private VC improved selection criteria focus on environmental impact, including circular economy and supply-chains	Private-led Fund of Funds, high management fees, difficult to monitor. High VC/institutional underlying fund private investment leverage, but only moderate venture financing additionality.	Regional venture pipeline considerations insufficient to meet socio-enviro goals. Cleantech definition and pioneering selection criteria were developed.
Program Design Learning	Enabled earlier stage VC funding, but too small to achieve follow-on, program extended by £25m to fund follow-on. Potential to improve path dependent grant peer review.	Too early to report.	Enabled earlier fund close, larger size funds. Upskilled FMs, increased syndication, foreign market penetration, follow-on and exits. Path	Evergreen fund not self-supporting at 10 years. Obtained second fund for follow-on and new investments into wider range

			dependent re no enviro impact measures.	of sectors, retaining enviro goals.

Sources: BIS (2012) Early assessment of UKIIF; IAP early assessment (unpublished, see Owen et al, 2020); LCIF (2015) Final evaluation; interviews with fund managers (FMs) and policymakers at BEIS, BBB and IUK for all programmes